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Key Points:

- Poya Terrane of New Caledonia contains slices of Campanian-late Paleocene marginal basin upper crust (Poya Terrane basalts) and Coniacian-Santonian passive margin sediments (Kone Facies)
- Poya Terrane originated in the lower plate of the subduction/obduction system and was locally affected by HP-LT metamorphism
- E-MORB sills were intruded into the ancient passive margin soon after inception of oblique subduction (circa 56 Ma)

Supporting Information:

- Supporting Information S1

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A Reappraisal of the Poya Terrane (New Caledonia): Accreted Late Cretaceous-Paleocene Marginal Basin Upper Crust, Passive Margin Sediments, and Early Eocene E-MORB Sill Complex

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Abstract The Poya Terrane of New Caledonia is a composite lithotectonic unit made of (i) Campanian-Paleocene enriched mid-ocean ridge basalt (E-MORB) and BABB-type (back-arc basin basalt) basalts and abyssal argillite (Poya Terrane basalts) and (ii) Coniacian-Santonian sandstone, turbidites, and abyssal argillite (Kone Facies) intruded by early Eocene E-MORB sills. Remapping reveals that the Kone Facies is more extensive than previously thought. Field data, petrography, and U-Pb geochronology of detrital zircons show that Kone Facies sediments have the same provenance as coeval autochthonous sediments (Formation a Charbon), albeit with more abundant contemporaneous zircons. They accumulated on the eastern continental slope of the Norfolk Ridge and eventually mixed with abyssal argillite. Temporally, sill emplacement is related to subduction inception at circa 56 Ma, thus suggesting a possible genetic link. We postulate that either (i) E-MORB intrusion was related to oblique extension and thinning of the down going plate or, alternatively, (ii) the "enriched" (off axis?) partial melt zone of the ancient ridge swept the lower plate continentward, generating E-MORB dikes in the upper marginal basin crust, and sills in passive margin sediments before it became extinct. Thereafter, sliced marginal basin upper crust, passive margin sediments, and associated dolerite sills were obliquely accreted to the fore-arc region, and in the NE part of the terrane, subducted and recrystallized into the blueschist facies. The Poya Terrane was eventually thrust onto the Norfolk Ridge when the latter reached the subduction zone and debris from the thrust sheet fed middle to late Eocene syntectonic basins. At the same time, mafic portions of the Poya Terrane were subducted at depth where they recrystallized into the eclogite facies, mixed with serpentinite to form the Pouebo mélange, and, finally, were exhumed in the fore-arc region. Finally, late Oligocene faulting and hydrothermal events overprinted the NE part of the terrane in probable connection with postobduction granitoid emplacement.

1. Introduction

In New Caledonia, an extensive mafic allochthon termed Poya Terrane (Cluzel et al., 1994, 2001; Cluzel, Maurizot, et al., 2012) underlies the Peridotite Nappe (Avias, 1967), one of the world's largest ultramafic ophiolites. Both structurally overlie autochthonous rocks of the Norfolk Ridge, which had rifted from south-eastern Gondwana in the Late Cretaceous. In the south of the island, peridotites are locally overlain by ultra-depleted ultramafic and mafic cumulates, which probably formed in a fore-arc setting (Cluzel et al., 2016; Marchesi et al., 2009; Pirard, Hermann, & O'Neill, 2013; Prinzhofer, 1987). The Peridotite Nappe is crosscut by early Eocene suprasubduction dikes (55–50 Ma) (Cluzel et al., 2006, 2016). Obduction occurred when the northern tip of the Norfolk Ridge (see below) jammed a NE dipping subduction zone.

In its original definition (Cluzel et al., 1997), the dominantly mafic Poya Terrane, sandwiched between the autochthonous/parautochthonous terranes and the Peridotite Nappe, was composed of tectonically sliced mafic volcanic rocks and abyssal sediments. In contrast with the Peridotite Nappe, the Poya Terrane does not exhibit any evidence for suprasubduction zone origin. Conversely, eclogite facies (e.g., subducted) equivalents of Poya basalts mixed with metaserpentinite occur in the Eocene HP-LT complex of northern New Caledonia (Pouebo Terrane) (Cluzel et al., 2001). Therefore, the Poya Terrane and its high-pressure

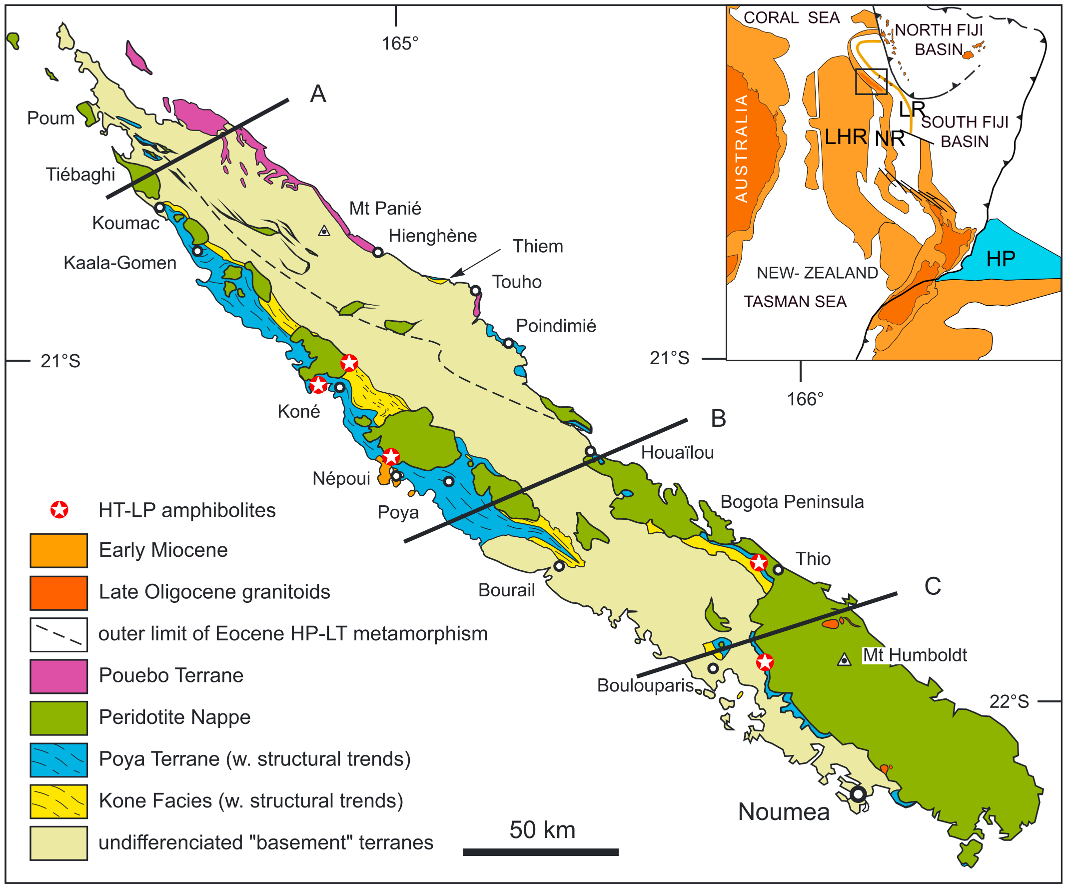

Figure 1. Geological sketch map of New Caledonia.

metamorphic equivalents represent a subduction complex formed by accretion and subduction of tectonic slices of the lower plate of the Eocene subduction-obduction system (Cluzel et al., 2001).

This accretion model is challenged by a recent reinterpretation of the ophiolite complex of New Caledonia, which suggests that both mafic and ultramafic allochthons were tectonically detached from the upper plate. The gravity-driven southwest directed slide of allochthonous units is being triggered by exhumation of HP-LT metamorphic rocks (Lagabrielle et al., 2013). Therefore, a reappraisal of the Poya Terrane has been undertaken, in order to determine its tectonic/geodynamic setting. Special attention has been given to the Koné Facies, a series of fine-grained clastic sediments and mafic volcanic rocks, which crops out near Kone and other localities along the west coast, and is closely associated with Poya Terrane basalts. This volcano-sedimentary unit has been largely underestimated in the past and diversely regarded a (i) an autochthonous unit: the Kone Formation of Carroué (1972) and Paris (1981), (ii) an integral part of the allochthonous Poya Terrane (the Kone Facies of Maurizot & Vendé-Leclerc, 2009), or (iii) a parautochthonous unit: the Kone Terrane (Cluzel, Maurizot, et al., 2012). This study includes remapping of Poya rocks in a strict sense and Koné Facies, petrography of sediments, detrital zircon provenance analysis, geochemistry, and U-Pb geochronology of mafic shallow intrusive rocks, as well as examination of relationships with HP-LT metamorphic complex, and leading to proposal of a refined tectonic-geodynamic model for the formation of Poya Terrane.

2. Geological Setting

New Caledonia corresponds to the emerged northern part of the Norfolk Ridge, a narrow submarine rise connected southward to New Zealand (Figure 1). This continental fragment rifted from Australia during Late Cretaceous time (Hayes & Ringis, 1973). The main island of New Caledonia is composed of volcanic, sedimentary, and metamorphic terranes, which were assembled during two major tectonic events:

assembly of an Early Cretaceous tectonic collage and Paleocene to late Eocene accretion followed by obduction/collision. Both events included periods of high-pressure metamorphism in connection with plate convergence in subduction zones. In summary, the geological evolution of New Caledonia comprised three main episodes:

1. The Gondwanan phase (Permian-Early Cretaceous) is marked by subduction along the SE Gondwana margin. At that time, proto-New Caledonia was located in a fore-arc region in which volcanic arc detritus accumulated, while accretion and subduction of oceanic and terrigenous material formed a mélange metamorphosed to blueschist facies.
2. During the Late Cretaceous to Eocene, marginal rifting isolated New Caledonia, and several marginal basins opened in possible connection with an eastward retreating Paleo-Pacific subduction zone. After a period of shallow-water terrigenous sedimentation associated with minor rift-related volcanic activity, only pelagic sediments accumulated. A new NE dipping subduction system initiated to the east of New Caledonia at the Paleocene-Eocene boundary (Cluzel et al., 2006; Cluzel, Jourdan, et al., 2012). This system generated the eclogite-blueschist complex of northern New Caledonia, consumed the eastern Australian Plate, and eventually ended with late Eocene obduction, when the northern part of Norfolk Ridge blocked the subduction zone.
3. Finally, during the post-Eocene phase, New Caledonia emerged; this episode mainly corresponds to post-obduction granitoid intrusion, tropical weathering of exhumed rocks, prominent regolith development, and minor tectonic events.

Pre-Late Cretaceous rocks in New Caledonia occur in three tectonostratigraphic units: Boghen, Koh-Central, and Teremba Terranes. The Boghen Terrane is a subduction complex consisting of schistose and disrupted volcano-sedimentary rocks, pillow basalt, chert, black shale, sandstone, tuffs, turbiditic greywacke, serpentinite, and mafic/ultramafic melange. These rocks have been metamorphosed to a notably higher grade (lower greenschist to blueschist facies) than the adjacent terranes (Cluzel et al., 1994).

The Koh-Central Terrane is a disrupted ophiolite suite of Early Permian age (Aitchison et al., 1998) that occurs locally along the central axis of the island. It is composed of gabbro, dolerite, rare plagiogranite, island arc tholeiites (IATs) and boninite pillow lavas, and undated abyssal chert directly overlying the pillow basalts (the Koh Ophiolite of Meffre et al., 1996). The Koh Ophiolite rocks are overlain by a thick succession of Triassic to Early Cretaceous deep water volcano-sedimentary rocks including black shale, volcaniclastic turbidite (greywacke), radiolarian-bearing siltstone, and chert (Meffre et al., 1996). The terrane has a distal and deep water character. Middle Triassic (Anisian) and Late Jurassic (Oxfordian-Kimmeridgian) faunas are correlated with those of the New Zealand Murihiku Terrane (Campbell et al., 1985; Meffre, 1995).

The Teremba Terrane is a succession of Upper Permian to mid-Jurassic proximal volcaniclastic and volcanic rocks (andesite, dacite, and rhyolite). The sedimentary rocks are typically medium-grained volcaniclastic turbidite with only minor argillite, some shallow-water volcaniclastic conglomerate, and rare black shale, a few tens of meters thick associated with thin quartzose sandstone. The terrane contains abundant faunas closely resembling those of the Murihiku Terrane of New Zealand (Ballance & Campbell, 1993; Campbell, 1984; Campbell et al., 1985, 2001; Grant-Mackie et al., 1977; Paris, 1981). The mineral, chemical, and isotopic compositions of greywackes suggest that Koh-Central and Teremba sediments are derived from a similar source, identical to volcanic and subvolcanic rocks of the Teremba Terrane (Adams et al., 2009).

The paleogeographic features of the three pre-Late Cretaceous terranes suggest that they formed during an episode of west dipping subduction. Faunal endemism, shared with New Zealand, and evidence from geochemistry and detrital zircon age data suggest that they are possibly related to an arc/fore-arc system in discontinuous isolation from Australia (Adams et al., 2009; Cluzel & Meffre, 2002; Meffre, 1995).

A pre-Coniacian unconformity postdates the final amalgamation of these terranes and exhumation of high-pressure metamorphic rocks of the Boghen Terrane, which occurred between the Albian (~100 Ma) and the Coniacian (~89 Ma) (Adams et al., 2009; Cluzel et al., 2011). Coniacian to Campanian conglomerate, shallow marine coal-bearing sandstones, and carbonaceous siltstones, termed "Formation à Charbon," rest with angular unconformity upon eroded older terranes. A temporal correlative of the Formation à Charbon referred to as the Diahot Terrane (Cluzel et al., 2001) exists in the HP-LT metamorphic complex of northern New Caledonia (see below). Metasediments of the Diahot Terrane consist of two units, Tondo and Pilou

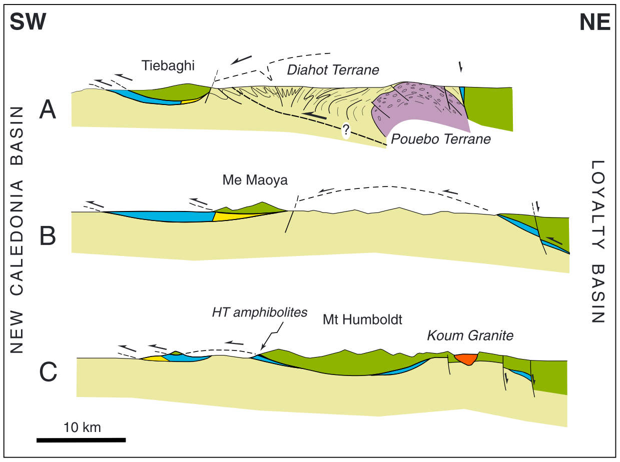

Figure 2. Sketch cross sections of New Caledonia to show the relationships between the diverse alochthonous units, HP-LT metamorphic complex, HT amphibolites (metamorphic sole), and postobduction granitoids.

Formations. Tondo Formation is chiefly composed of disrupted conglomerate, sandstone, and siltstone of possible turbiditic origin. Pilou Formation is much finer grained and dominantly consists of carbonaceous schists with extremely rare and thin sandstone layers, bimodal volcanic rocks, and associated volcanogenic sulfide deposits. Sandstones of the Formation à Charbon and those of Diahot Terrane yield detrital zircon populations derived from (i) Late Cretaceous (Coniacian) subcontemporaneous volcanic activity, (ii) uppermost Lower Cretaceous (Albian) greywackes (?), and (iii) directly underlying basement terranes (Cluzel et al., 2011).

The Paleogene evolution of New Caledonia was characterized by progressive inundation due to postrift thermal subsidence and development of Maastrichtian to mid-Eocene hemipelagic to pelagic sedimentation. Meanwhile, marginal basins opened on both sides of the Norfolk Ridge (Tasman Sea, New Caledonia, and South Loyalty-South Fiji basins). Whether ultrawide extension of the former East Gondwana margin was related to eastward slab retreat is still an unsolved issue (e.g., Cluzel et al., 2010) because the corresponding Late Cretaceous-Paleocene volcanic arc remains unknown. Finally, the northern part of New Caledonia entered a new north or northeast dipping subduction zone that initiated at ~56 Ma (Cluzel, Jourdan, et al., 2012) and an Eocene high-pressure metamorphic belt developed in the northernmost part of the island. Meanwhile, imbricate thrusting and a foreland bulge provoked southward propagating basin inversion and prominent erosion in the middle part of the island.

The HP-LT belt comprises mafic blueschist and eclogite facies rocks and metasediments that recrystallized in a NE dipping subduction zone. Maximum pressures of ~24 kbar and temperatures of ~650°C are recorded by relict eclogite facies assemblages (Carson, Powell, & Clarke, 1999; Clarke, Aitchison, & Cluzel, 1997; Vitale Brovarone & Agard, 2013). Peak metamorphic conditions were probably reached during the early Eocene (~44 Ma, U-Pb dating of metamorphic zircon overgrowths) (Spandler, Rubatto, & Hermann, 2005). Mafic eclogites in the Pouebo mélange have Late Cretaceous to Eocene protolith ages and share geochemical affinities with Poya Terrane basalts (Cluzel et al., 2001; Spandler et al., 2005). The high-grade Pouebo eclogites now form the core of a large antiformal structure wrapped by Diahot schists and are in turn thrust over low-grade autochthonous or parautochthonous rocks of the west coast (Figure 2a). Exhumation of HP-LT metamorphic rocks likely occurred along the subduction channel (Cluzel et al., 2012; Vitale Brovarone & Agard, 2013) and took place between 40 Ma and about 34 Ma, as indicated by U-Pb on zircon, $^{40}Ar/^{39}Ar$ on phengite, and apatite fission tracks data (Baldwin, Rawlings, & Fitzgerald, 2005). The NW-SE trending regional upright foliation is deformed by kilometer-scale folds with steeply plunging axes (Cluzel et al., 2001; Maurizot et al., 1989), which indicate regional-scale dextral shearing.

Meanwhile, two extensive allochthonous terranes, referred to as the Poya Terrane and Peridotite Nappe, respectively (Figures 1 and 2), were successively emplaced during the Eocene. The lower allochthonous unit termed Poya Terrane (or Nappe) (Aitchison, Clarke, et al., 1995; Cluzel et al., 1994, 2001) is a major geological element of New Caledonia and is exposed on both coasts of the island. The main body is approximately 200 km long and 10 to 25 km wide and crops out along the west coast. Less extensive units crop out discontinuously along the east coast (Figure 1). The Poya Terrane comprises massive basalt (flows or sills?), pillow lavas, and abyssal sediment lenses, all of which are locally crosscut by dolerites. The Poya Terrane resulted from off-scrapping and slicing of the uppermost levels of the lower plate crust in front of the intraoceanic Loyalty Arc (Cluzel et al., 2001), forming a mafic subduction complex with some rare interleaved serpentinite lenses (Cluzel, Maurizot, et al., 2012; Dilek, 2003; Wakabayashi & Dilek, 2000). This unit was thrust over autochthonous rocks of the Norfolk Ridge during the late Eocene as recorded by syntectonic sedimentation in southwestward migrating foreland basins, which contain upward coarsening units dominated by mafic clasts (Cluzel et al., 1998; Maurizot & Cluzel, 2014). It is worth noting that except in northernmost and slightly older subbasins, which were solely derived from parautochthonous sedimentary units, even the topmost levels (proximal coarse breccia and olistostrome) of the foreland basins consistently record a mixed sedimentary (parautochthonous sedimentary cover) and magmatic (oceanic crust) provenance.

Monogenetic breccias are scarce and only occur in probable connection with collapse of unstable cliffs of basalt, limestone, or black chert. This may denote an origin from a southwestward moving thrust complex composed of both parautochthonous units (Montagnes Blanches Nappe) (Maurizot, 2011) and the Poya Terrane. Notably, no component of the Peridotite Nappe exists in syntectonic breccias. The Poya Terrane and autochthonous/parautochthonous terranes were in turn overthrust by the Peridotite Nappe in latest Eocene or earliest Oligocene time (Cluzel et al., 1998).

The Peridotite Nappe (Avias, 1967), one of the world's largest ultramafic allochthons, originally covered most of the island. However, several phases of erosion left remnants of tectonic klippes spread along the west coast and a larger unit named "Massif du Sud" in the south of the island. Kinematic indicators in the highly sheared serpentinite sole, 20–200 m thick, generally indicate top to the SW thrusting (Quesnel et al., 2016). The Peridotite Nappe is dominantly composed of harzburgite (>80%), dunite, and minor lherzolite (in northernmost massifs only), which represent elements of a prominently depleted suprasubduction mantle lithosphere (Prinzhofer, 1987). Ultramafic rocks of the Peridotite Nappe display a shallow-dipping compositional layering which locally bears a high-temperature stretching lineation formed by elongated or boudinaged orthopyroxene grains and elongated streaks of chromite with an average N-S trend. Zones of upright high-temperature foliation that locally occur, independently of postobduction tilt (Bogota Peninsula, Poum, and Tiebaghi massifs; Figure 1), have been interpreted as paleotransform faults (Leblanc, 1995; Prinzhofer & Nicolas, 1980; Titus et al., 2011), which suggest WSW-ENE and WNW-ESE original orientation of the associated spreading ridges.

Plagioclase and spinel-bearing lherzolites of the northern massifs, secondarily reenriched by near-ridge melt circulation, may have generated MORB-like magma (Secchiari et al., 2016; Ulrich et al., 2010). In contrast, owing to their extreme depletion in incompatible elements compared to primitive mantle composition, residual harzburgites and dunites, which form the bulk of Peridotite Nappe, underwent over 20–30% partial melting, most probably during several episodes of magma production and cannot have been in equilibrium with MORB-like magma (Marchesi et al., 2009; Pirard et al.,2013; Prinzhofer & Allègre, 1985). Whole rock and mineral chemical constraints allow a complex evolution to be drawn, from reenrichment by circulating melts during oceanic accretion to mantle metasomatism during subduction (Marchesi et al., 2009; Pirard et al.,2013; Secchiari et al., 2016; Ulrich et al., 2010).

Harzburgites and dunites in the Massif du Sud are overlain by dunite, pyroxenite, wehrlite, and gabbro cumulates (Prinzhofer, 1987). Cumulate wehrlite and gabbro-norite (enstatite gabbro) probably crystallized from ultradepleted melts (Marchesi et al., 2009; Pirard et al., 2013). Partial melting and melt fractionation modeling suggest that gabbro-norite cumulates formed in equilibrium with clinoenstatite-bearing boninites. The latter were formed by high-temperature hydrous melting of the mantle wedge enriched by MORB-like slab-derived melts and fluids during the early stage of Eocene subduction (Cluzel et al., 2016). The final melting episode was followed by postmelting diffusion of incompatible elements that may account for extreme depletion of dunites on top of the ultramafic pile (Pirard et al., 2013; Prinzhofer, 1987). It is worth noting that no remnants of earlier MORB-like crust are preserved and that boninite-related cumulates rest directly upon dunites. The boninitic upper crust itself is not preserved in the present geological record on the island and, except for cumulate gabbro, was eroded before/during obduction.

Discontinuous amphibolite lenses (hundreds of meters to kilometers in size) pinched between the serpentinite sole and Poya Terrane record recrystallization of oceanic crust rocks (basalt and abyssal argillite) at high temperature (~800–950°C) and low pressure (~0.5 MPa). Amphibolites and crosscutting granulite-facies dikes have a pre-70 Ma protolith and recrystallized at ~56 Ma ($^{40}Ar/^{39}Ar$ hornblende and U-Pb zircon and sphene) (Cluzel, Jourdan, et al., 2012). Therefore, inception of intraoceanic subduction that eventually led to obduction occurred in latest Paleocene time within a hot and young oceanic lithosphere, e.g., at or near an oceanic ridge. Amphibolites are geochemically similar to back-arc basin basalts (BABBs) characterized by MORB-like rare earth element (REE) and trace element compositions and moderate Nb depletion (Cluzel, Jourdan, et al., 2012) and likely represent the composition of the lower plate crust when it was subducted beneath the hot young lithosphere of the future Loyalty Basin.

The Peridotite Nappe is crosscut by a variety of early Eocene dikes (55–50 Ma) (Cluzel et al., 2006), which are not present in the Poya Terrane. These dikes comprise medium- to coarse-grained rocks, the compositions of which vary from ultramafic (pyroxenite and hornblendite) to felsic (diorite, leucodiorite, and granite), and

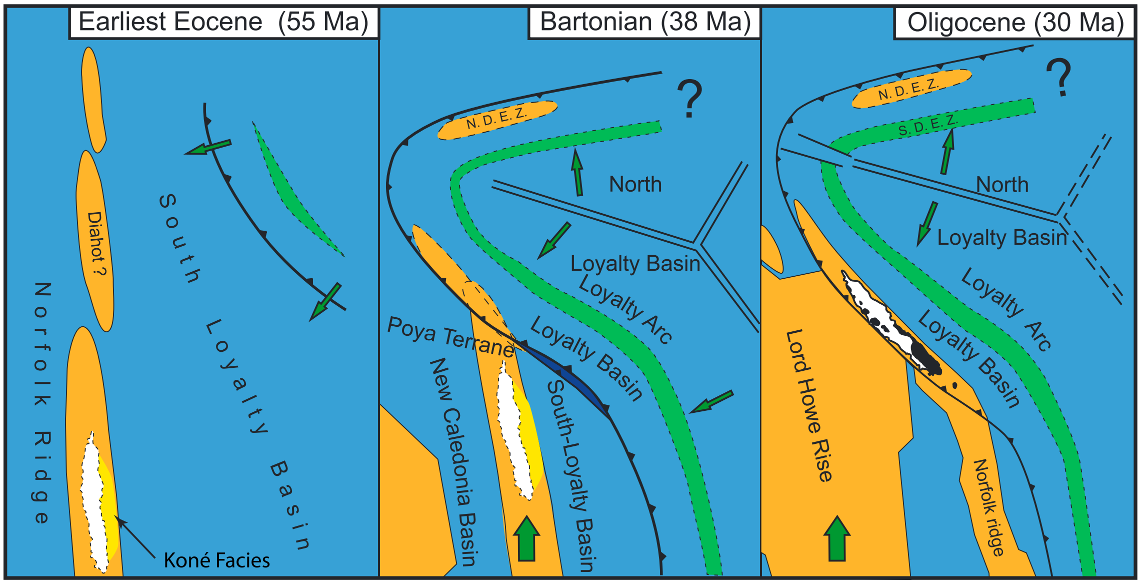

Figure 3. A model for the tectonic evolution of the Loyalty Arc from Paleocene subduction inception to late Eocene obduction and subduction blocking (after Cluzel et al., 2001). Original locations of (left) Kone Facies (yellow) and (middle) Poya Terrane basalts (dark blue) are shown.

minor basalt (dolerite). The majority of felsic dikes are interpreted to be slab melts formed by partial melting of diverse MORB-like oceanic mafic rocks including gabbro cumulates (Cluzel et al., 2006). However, some of the felsic dikes have geochemical affinity with boninites and have been referred to as "boninite series," formed by melting of previously depleted mantle wedge reenriched by slab melts and fluids (Cluzel et al., 2016). In contrast, the scarce slightly younger (50 Ma) and shallower dolerite dikes, which crosscut gabbro-norite cumulates as well, display suprasubduction affinities (island arc tholeiites, IATs) and likely represent the product of partial melting of "normal" (i.e., fertile) mantle wedge in an infant fore arc.

At variance with widespread opinion (Crawford et al., 2003; Eissen et al., 1998; Lagabrielle et al., 2013) boninite is absent from the Poya Terrane and cannot be taken as an evidence for its suprasubduction origin. Actually, the clinoenstatite boninite of Nepoui, which is enclosed in the serpentinite sole, may be genetically related to the early Eocene suprasubduction dike complex of the Peridotite Nappe and to gabbro-norite cumulates (Cluzel et al., 2006, 2016). Similarly, the composition of latest Paleocene (56 Ma) high-temperature amphibolites of the metamorphic sole and lower Eocene slab-derived dikes of the Peridotite Nappe suggests that the subducted slab crust had N-MORB or BABB composition.

3. Loyalty Islands

Considering the geometry and polarity of the Eocene subduction/obduction system, the Loyalty Islands, which represent the emerged part of the largely submarine Loyalty Ridge that runs parallel to the NE of the Norfolk Ridge, for more than 1300 km, likely represent the corresponding volcanic arc (Figure 3). Although this view has been largely accepted, despite many investigations, no rock forming the basement of the Loyalty Islands has been recovered. The only indirect evidence comes from the northern extension of the Loyalty Arc in the South D'Entrecasteaux Zone and in the North Loyalty Basin. In the former, results from Ocean Drilling Program sites 830 and 831 indicate that Bougainville seamount is formed of middle Eocene (40 Ma, $^{40}Ar/^{39}Ar$) (Mortimer et al., 2014) andesite overlain by 700 m thick limestone. Deep Sea Drilling Project site 286 drilling in the North Loyalty Basin has crosscut 650 m of middle to late Eocene volcaniclastic and tuffaceous rocks of volcanic arc affinity. The continuous morphology of the basin and ridge system and negative gravity anomaly support correlation of the northern and southern parts of this hook-like structure. Based upon this view, a coherent model of evolution of Lord Howe, New Caledonia, and Loyalty ridge and basin system has been suggested (Cluzel et al., 2001) and will be taken into consideration in this article (Figure 3).

4. Postobduction Intrusive Rocks

In the south of Grande Terre, two kilometer-size plutons (Saint Louis and Koum) crosscut the Peridotite Nappe and its autochthonous substrate (Figures 1 and 2) and thus postdate obduction. Saint Louis and Koum plutons display roughly elliptical shapes and are surrounded by a number of meters to tens of meters thick subvolcanic dikes. U-Pb zircon geochronology provided late Oligocene ages for St. Louis granodiorite (27.4 ± 0.2 Ma) and Koum granite (24.3 ± 0.1 Ma) (U-Pb thermal infrared multispectral scanner) (Paquette & Cluzel, 2007). Both plutons yielded scarce inherited Paleozoic zircon cores possibly coming from assimilation of basement xenoliths (Paquette & Cluzel, 2007). Late Oligocene granitoids display the geochemical and isotopic features of active margin magmas with almost undecipherable contamination by continental crust rocks shown by Nd-Sr and Pb isotope data. These rocks have been interpreted as a result of short-lived subduction along the west coast accompanied or followed by breakoff of the older slab (Cluzel et al., 2005).

Within the Peridotite Nappe, late Oligocene intrusive rocks are associated with silicification and carbonation of peridotite (listwanite). Both granitoids and listwanite host epithermal and porphyry-type sulfide mineralization. Granitoids and listvenite are the magmatic and hydrothermal consequences of the same event. The occurrence of listwanite associated with epithermal mineralization independently of granitoid outcrops suggests that concealed intrusive bodies may exist at depth. Minor normal faults that crosscut the granitoids and subsequent transcurrent reactivation highlight post-Oligocene tectonic events also identified along the eastern margin of New Caledonia (Chardon et al., 2008).

5. Transition Between Poya Terrane and Eocene HP-LT Metamorphic Complex

In northern New Caledonia elements of the Poya Terrane and Peridotite Nappe are involved in recumbent west verging folds where they form irregular lenses pinched in synclines. The metamorphic grade of these lenses increases from west to east as in the rest of the HP-LT complex. Peridotites form gentle synforms prolonged downward by highly schistose serpentinites pinched in narrow slivers, a few tens of meters thick and several kilometers long (Gautier et al., 2016; Maurizot & Vendé-Leclerc, 2009). These peridotite-serpentinite units contain boudinaged and sheared early Eocene dikes similar to those in the Peridotite Nappe and thus may be directly correlated with it. In contrast, no direct equivalent of the Poya Terrane exists; instead, blocks of dolerite, basalt, red chert, and leucodiorite occur within mélange with a matrix of sheared serpentinite. The eclogitized Pouebo mélange contains meters to 100 m size blocks of E-MORB eclogites, which could be metamorphosed dolerites of the Kone Facies (see U-Pb geochronology section below).

6. Transported Piggyback Basins

Turbidite successions, referred to as the Nepoui-Koumac Flysch and Olistostrome, are closely associated with Poya basalts in Nepoui and Koumac areas and likely represent transported piggyback basins (Figure 1; note that these occurrences are two small to be represented on the map). Both basins are tectonically pinched between the Poya Terrane and the Peridotite Nappe. The Nepoui Flysch starts with 2–5 m thick biocalcarenite of imprecise age (Bartonian-Priabonian) (Paris et al., 1979; Meffre, 1995; Cluzel, 1998) that rests directly upon serpentinite. Significantly, the basal limestone contains large benthic foraminifers, together with some detrital serpentinite and chromite grains. It is overlain by pale brown argillite and alternating coarse arenite and dolomicrite. On top of arenite beds, thin (2–5 mm) layers or lenses of reworked red argillite, which appear locally, very closely resemble those of the Poya Terrane. Soft sediment deformation (slumps) is widespread. Arenite clasts are derived from three distinct sources: Poya Terrane basalt (clinopyroxene, ilmenite, and magnetite), an adjacent shallow-water platform (carbonate bioclasts), and serpentinite. It is worth noting that the arenites contain no fresh peridotite rock or ultramafic mineral clasts such as chromite. They also lack any high-pressure metamorphic detritus. The fine-grained beds, 2–10 cm thick, have yielded an uppermost Eocene (Priabonian) pelagic microfauna. Near Koumac (north) an olistostrome, ~300 m thick, displays several mass flow units, 5–10 m thick, composed of basalt boulders embedded in a matrix of sandy breccia made of pillow and chert fragments with some lenses of red blocky argillite. Basalt fragments display the same geochemical features as the dominant facies of Poya basalt (E-MORB) (Cluzel et al., 2001). On top of the mass flow unit, a few rafted basalt boulders are overlain by an ~50 m thick section of alternating sands and dolomicrite. The Nepoui-Koumac Flysch probably accumulated in piggyback basins located at, or close to, the boundary between the Poya Terrane and exhumed serpentinites of the fore-arc region. The apparent absence of clasts of terrigenous lithologies of the Koné Facies suggests that flysch formation occurred in connection with Poya basalts before the tectonic amalgamation of Kone and Poya rocks in one single terrane.

7. Poya Terrane and Kone Facies

The large allochthonous unit termed Poya Terrane (Cluzel et al., 1997) crops out along the west coast in a region of low-elevation grasslands and, sporadically, in smaller lenses along the east coast. The Poya Terrane has only scarce and deeply weathered outcrops; however, new man-made exposures due to the economic development of the area reveal that the extent of the dominantly sedimentary component termed Kone Facies had been largely underestimated and actually constitutes about one third of the area/volume of the terrane (Figure 1). The larger units of Kone Facies crop out on the northeastern side of the terrane. However, smaller lenses of clastic sediments also appear at several places tectonically intercalated with basalt and abyssal argillite of undoubtedly oceanic origin. In contrast with the low hills formed by Poya basalts, Kone Facies rocks define steep elongate ridges reinforced by upright dolerite sills, which can be followed over several kilometers. A detailed field survey confirms that Poya Terrane basalts and Kone Facies rocks are associated in one single tectonic unit thrust upon Late Cretaceous to Eocene autochthonous rocks.

The Poya Terrane in a strict sense comprises slices of upper oceanic crust (basalt and abyssal sediments), metamorphosed (zeolite to lower greenschist facies) by both burial and "hydrothermal" (ocean floor) metamorphism (Cluzel et al., 2001; Nicholson et al., 2000) and crosscut by a vein network filled with quartz, epidote, chlorite, zeolite, and sulfides. Typically red and more rarely white, green, or dark brown colored cherts and argillites are dominantly composed of aluminous clay (illite) and zeolite minerals, which may be derived from felsic (suspensions of continental origin or volcanic ashes) and hydrothermally altered mafic (ocean basalt) sources, respectively. Small-scale Fe-Mn crusts and polymetallic sulfide ore appear locally. Diversely colored radiolarian cherts appear in coherent beds and in elongated nodules 2–5 cm thick. Abyssal argillites form upright lenses, 20 cm to 5 m thick, rarely interpillows, never contain macrofossils but yield Campanian to late Paleocene or earliest Eocene radiolarians (Aitchison, Meffre, et al., 1995; Cluzel et al., 2001). Clastic rocks directly associated with basalt are rare but significant. Pale red fine-grained quartz-bearing calcarenite 40 cm thick occurs about halfway between Bourail and Poya, where it is associated with pink limestone and pale red argillite and on the northeastern flank of the Koniambo Massif near Kone (laminated sandstone in red chert). Gray siltstones and argillites 15 m thick also appear at a single locality associated with basalt but are also found associated with coherent Kone Facies unit near Kaala-Gomen. Scarcely, in some sediment lenses, chert beds have been disrupted and form intraformational breccia (mélange) with subrounded clasts embedded in red abyssal argillite, thus suggesting soft-sediment deformation (supporting information Figure S1d). It is worth noting that such breccias are strictly intraformational and never contains basalt clasts.

Some Poya Terrane basalts display the geochemical features of oceanic plateaus (E-MORB) and had been interpreted as such (Cluzel et al., 1997). However, their association with abyssal argillite suggests eruption at depths not less than 3,000 m and they cannot have formed a massive plateau such as Ontong Java (Kroenke, 1972). Instead, eruption of enriched basalts is a feature of some modern SW Pacific back-arc basins, such as Lau Basin (Volpe et al., 1988) and North Fiji Basin (Eissen et al., 1998), and their association with (apparently) minor back-arc basin basalts (Cluzel et al., 2001) supports this interpretation (see discussion below). The dominant proportion (80%) of E-MORBs relative to other basalts types (BABB and OIB) in the database (Cluzel et al., 2001) is probably due to a sampling bias. All these rocks are covered by 5–20 m thick regolith in which mainly unweathered boulders of dolerite remain; therefore, E-MORB dolerites are overrepresented compared to other basalt types.

According to the original definition, Koné Facies is composed of interbedded, khaki-colored cherts, siltstones, and argillites with some fine- to medium-grained sandstones (Carroué, 1972; Paris, 1981), which actually correspond to distal turbidites. Bed thicknesses are typically 2 to 10 cm, with thickly bedded or massive units rarely encountered (supporting information Figure S1, Plate 1b). It is worth noting that in contrast to the autochthonous Formation à Charbon of about the same age, Kone Facies has no known basement and faulted boundaries with surrounding rocks are ubiquitous.

In contrast with intensely disrupted Poya Terrane in a strict sense, Kone Facies forms large coherent units, and even if continuous sections are rarely over 100 m across and prevent accurate stratigraphic correlations, transition between different lithologies may be observed at several localities. A somewhat abrupt (within 10 m) change from south dipping sandstone into fine-grained (silt/argillite) turbidite may be observed along the Kone-Tiwaka road (WGS 84: 164.9014; −21.0711; supporting information Figure S1a). Transition between khaki fine-grained turbidites and red or dark brown argillite-chert succession similar to the usual Poya abyssal sediments may be observed along the RT1 (main road) to the NW of Bourail (165.428; −21.4906), at Tribu de Boyen (164.615; −20.832) and in many other localities. Therefore, it may be considered that the bulk of Kone Facies rocks represent one single fining upward sequence evolving from relatively coarse sandstone into distal turbidites and finally abyssal argillite and chert. Sandstones show compositional variation from well rounded and well sorted to angular and poorly sorted, with local intraformational reworking. Lateral continuity is rarely seen over large distances. In contrast with the autochthonous Formation à Charbon, which contains rift-related mafic and felsic volcanic rocks, no contemporaneous volcanic rocks exist in Kone Facies, and carbonaceous rocks are also lacking. The lack of coeval interlayered volcanic rocks (see U-Pb geochronology section below) contrasts with the large zircon population of Late Cretaceous age (see below).

The presence of marine macrofossils, such as inoceramids, and recrystallized radiolarian “ghosts” in chert undoubtedly indicate marine deposition. Although it represents a minor component in the Kone Facies, sandstone is important in respect of the sedimentary processes involved and sediment provenance. Sandstones typically occur in beds, a few millimeters to a few centimeters thick (supporting information Figure S1, Plate 1a), in which grain size varies from very fine to coarse sand, with the majority of samples comprising grain sizes of 125–500 μm (supporting information Figure S1, Plate 2). They are generally well sorted but display variable grain sphericity and rounding and generally lack current features such as graded bedding or cross bedding. The ungraded and laminated nature of the sandstones, overall fine-grain texture, abundance of interbedded cherts, and argillites and local synsedimentary deformational structures (slumps and soft sediment boudinage) suggest deposition of sandy turbidites by aggradation from sustained high-density mass flows on the continental slope.

Quartz and feldspar (albite) are the dominant clastic minerals, cemented by interstitial calcite, which most probably originates from albitization of detrital feldspar of volcanic origin. Instead, many sandstone samples have been secondarily silicified during burial, diagenesis, and dolerite intrusion, and identification of grain boundaries may be difficult. The source of the silica is from both shale and sandstone beds. From shales, the most likely important silica sources include clay transformation, chiefly illitization of smectite, dissolution and pressure solution of detrital grains, and dissolution of opaline skeletal grains (radiolarians). From sandstones, silica sources include pressure solution of detrital quartz grains at grain contacts, feldspar alteration and dissolution, and possibly carbonate replacement of silicate minerals (McBride, 1989).

According to the relative abundances of quartz, feldspar, and lithic clasts, sandstones may be loosely categorized in the field as being intermediate between siliciclastic and volcaniclastic. The point counting method on stained polished slabs developed by Gazzi (1966) and Dickinson (1970) has been used together with petrographic analysis of thin sections to characterize more accurately the provenance of sandstones. The Koumac, Koné, and Bourail sandstones plot reasonably close to each other within the recycled orogenic section of the diagram, and each region is also closely grouped in terms of composition (Figure 4). Sandstones from the Bourail region, for example, are more quartz rich than sandstones from other localities. The Kaala-Gomen, Temalaand Bouloupari sandstones tend to plot on the edges of the Transitional Arc and Dissected Arc fields. However, within each group of outcrops, sandstones of different provenances may appear together. It is worth noting that no rock fragments from the HP-LT Boghen Terrane have been identified, probably because these rocks provide low-resistance clasts, which are commonly not preserved during sedimentary transport. The weak correlation between geographical location and sandstone composition probably results from tectonic disruption and remixing, and the differences that appear between them probably reflect the mixed nature of their source.

The composition of argillite beds has been investigated using X-ray powder diffraction (XRD) and short wave infrared (SWIR) spectroscopy. All samples dominantly contain quartz (~30%) and similar contents of albite together with illite, minor smectite, and montmorillonite. Illite, which dominates in almost all samples, may directly result from the weathering of felsic rocks under cool climate conditions or indirectly from

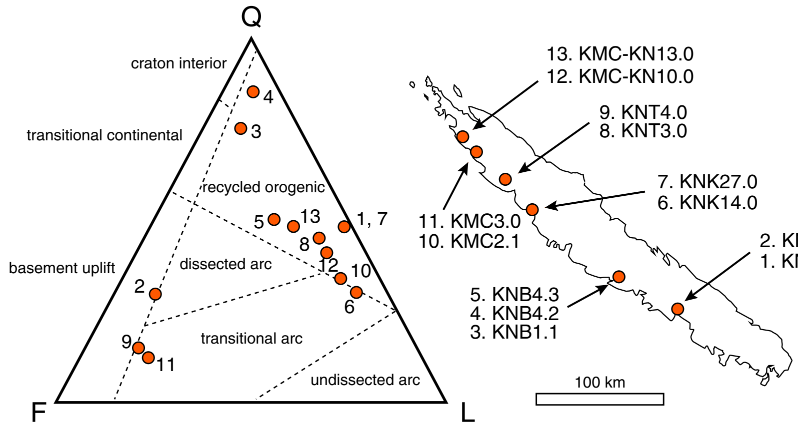

Figure 4. Ternary plot of Koné sandstones displaying the relative amount of quartz, feldspars (plagioclase and potassium feldspar), and lithic clasts, using the Gazzi (1966) and Dickinson (1970) method of point counting.

illitization of smectite during burial diagenesis. As smectite is derived from a mafic igneous source, it is likely that illite in these samples is a product of the illitization process. SWIR analysis also detected the presence of minerals of the mica family: phengite (SiMg-rich aluminous mica), paragonite (Na-rich aluminous mica), and clinochlore (Mg-rich chlorite). Magnesium-rich phengite may have been produced by illitization of smectite. If so, this same process may have occurred in samples that contain montmorillonite, which is derived from smectite in an alkaline environment. However, phengite, paragonite, and clinochlore are common mineral of rocks that have been subjected to blueschist facies metamorphism.

Available evidence suggests that argillite beds are derived from both mafic and alumina-silicate igneous sources with some contribution of HP-LT metamorphic rocks, which is advocated by the current association of phengite, paragonite, and clinochlore. Sources potentially exist in the pre-Late Cretaceous terranes of New Caledonia, which contain mixed felsic and mafic volcano-sedimentary rocks (Koh-Central and Teremba Terranes) and HP-LT metamorphic rocks (Boghen Terrane).

The formation is intruded by dolerite sills, a few meters to 100 m thick, forming elongated ridges, some of which may be traced over several kilometers. The intrusion of dolerite had the effect of locally recrystallizing the sediments (nodular "schist" to hornfels) by contact metamorphism (supporting information Figures S3a–S3d). Therefore, finely recrystallized siltstones have sometimes been mistaken for chert. Only one outcrop contained a mafic dike, which crosscuts the bedding. Sills do not display chilled margins and are generally medium grained. Large (50–100 m thick) dolerite sills may be coarse grained in their inner parts with centimeter-size nodular aggregates of pyroxene and may be termed gabbro (e.g., Audet, 2008; Maurizot & Vendé-Leclerc, 2009). Thus, they cooled slowly and were probably not connected upward to the surface. Dolerite sills locally (i.e., RT1 near Kone, west coast, and Thiem Bridge near Touho, east coast) contain large enclaves (up to 10 m) of fine-grained Kone Facies sediments, totally recrystallized into hornfels. Except in the northern part of east coast units, which have been involved in the Eocene HP-LT complex (see metamorphism section below), dolerite sills never display internal (ductile) deformation or striated boundaries, which could advocate syntectonic emplacement.

8. Paleontology

Dominantly, fine-grained turbidites generally contain few macrofossils. This is also the case for siltstones and argillites of the Koné Facies, which contain scarce external casts of fossil inoceramid shells, some of which reach more than 20 cm in diameter. In spite of their adaptation to a wide range of benthic environments, inoceramids generally tended to live in upper bathyal and neritic ecosystems (Harries et al., 1996). Therefore, their occurrence in deep water distal turbidites is somewhat puzzling unless large thin shells were rafted downslope with the enclosing sediments. The Kone Facies rocks yielded *Inoceramus australis* (Paris, 1981), which represents the Piripauan stage of New Zealand (uppermost Coniacian to Middle Santonian) (Crampton et al., 2000), and *Inoceramus (Sphaenoceramus) angustus* of Upper Santonian-Lower

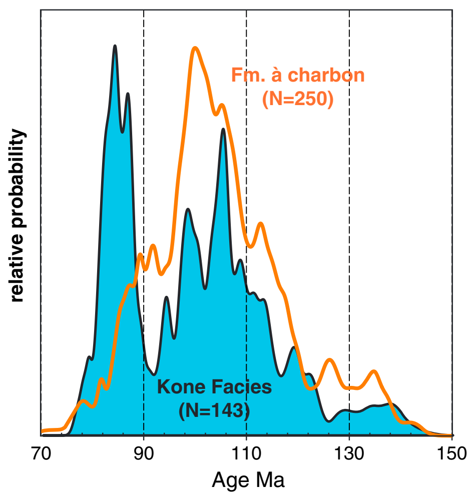

Figure 5. Comparison of Cretaceous detrital zircon age populations to show the prominent importance of Coniacian-Santonian (synchronous) zircon population in Kone Facies compared to Formation à Charbon (supporting information Data Set S1).

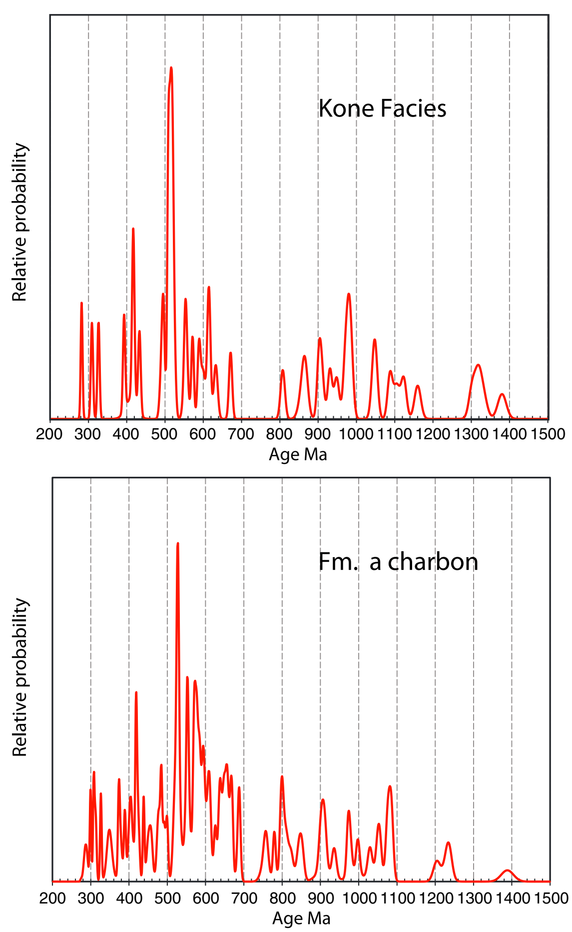

Figure 6. Paleozoic-Proterozoic detrital zircon age populations of the Late Cretaceous Formation à Charbon and Kone Facies (supporting information Data Set S1).

Campanian affinity (Tröger, 2000). These assignments make the Kone Facies almost synchronous with Formation à Charbon (Coniacian-Campanian). In contrast with such relative macrofossil paucity, abundant radiolarians are present in most thin sections of fine-grained siltstone and chert containing circular or elliptical impressions that represent more or less recrystallized radiolarian skeletons. Eighteen representative samples of chert, siltstone, and argillite have been digested in diluted HF for extracting radiolarians as a means of constraining the age of the formation. Of the samples etched, radiolarians were recovered from only seven samples. Unfortunately, petrographic and scanning electron microscope imaging of the extracted radiolarians show that all had been recrystallized and could not be determined. In summary, on the basis of macrofossils only, the Kone Facies may be assigned to the uppermost Coniacian to Lower Campanian (~87–80 Ma), a correlation consistent with detrital zircon data (see below).

9. Detrital Zircon Provenance

A detrital zircon study was undertaken on 10 representative samples of siliciclastic, volcaniclastic, and greywacke-like sandstones. The obtained data were compared to those from the autochthonous Late Cretaceous Formation à Charbon of about the same age. Details of detrital-zircon preparation procedures, laser ablation inductively coupled plasma–mass spectrometry (LA-ICPMS) dating techniques, and U-Pb data treatment are given in supporting information Text S1.

All sandstones contained relatively young, euhedral zircon crystals and older, rounded crystals. The distribution of combined ages of all 225 zircons from the 10 samples shows a main Cretaceous population, a lesser Early Mesozoic group, and a minor Paleozoic-Precambrian group (Figures 6 and 7, supporting information Figures S6a and S6b, and Table S1). The distribution of Cretaceous zircons shows two distinct age peaks at 104 Ma (Albian) and 83 Ma (Coniacian-Santonian). Age-probability plots for individual samples show that all of the Koné sandstone samples have similar detrital zircon patterns differing mostly in the magnitude of the youngest Coniacian-Santonian population with respect to the Albian and older zircon populations (Figure 5). The Coniacian-Santonian zircon population is very close to the sediment age determined upon paleontological grounds and likely related to a synchronous magmatic activity, consistent with the volcaniclastic character of most of the sandstones. The prominent Albian zircon population is widespread in Upper Cretaceous sedimentary rocks of New Caledonia (Cluzel et al., 2011) and New Zealand (Adams et al., 2013a, 2013b, 2016). Albian rocks are only poorly represented in New Caledonia by scarce volcaniclastic turbidites that share the same origin as the rest of Mesozoic greywackes from the basement terranes (Adams et al., 2009; Cluzel et al., 2011). Therefore, Early Cretaceous zircons may locally be derived from volcanic or volcaniclastic rocks that were eroded before the Late Cretaceous or, alternatively, from an external source of this age such as the silicic Eastern Australian Whitsunday Province (Bryan et al., 2000, 2012).

Zircon age data for the Upper Cretaceous Formation à Charbon similarly display a predominant Cretaceous and a minor Precambrian-

Paleozoic "Gondwanian" population (Adams et al., 2009; Cluzel et al., 2011). In contrast with Kone Facies, the distribution of Cretaceous zircons is not clearly bimodal; however, younger Coniacian and older Albian populations coexist, thus suggesting that the Kone Facies depocenter was closer to the Late Cretaceous volcanic source. The pre-Cretaceous zircon populations slightly differ from place to place depending upon the nature of the directly underlying terrane, thus suggesting local derivation (Cluzel et al., 2011).

A formal comparison of pre-Cretaceous zircon age populations of Kone sandstones with individual samples of pre-Late Cretaceous basement terranes using the Kolmogorov-Smirnov test (Whitten, 2015) (not presented) shows a greater similarity with zircon populations of greywackes of the basement terranes that crop out on the eastern slopes of New Caledonia (Central Terrane).

10. Dolerite Geochronology

Previous attempts to date Poya Terrane basalts have proven difficult as a consequence of tropical weathering and widespread low-grade metamorphism. However, Paleocene to Eocene K-Ar ages (59 ± 6 to 38.5 ± 1.5 Ma) were suggested by Guillon and Gonord (1972) and more recently (61.6 ± 2.8 to 39.7 ± 2.1 Ma) by Eissen et al. (1998). The apparent ages of these slightly metamorphosed rocks are somewhat younger than the fossil (radiolarian) ages obtained from the associated abyssal sediments (83.5–55 Ma) (Aitchison, Meffre, et al., 1995; Cluzel et al., 2001); thus, they have been regarded unreliable and discarded. Therefore, without attempting to date the basalts again, in situ LA-ICPMS U-Pb geochronology has been undertaken on microzircons of 12 dolerite dikes/sills that crosscut the sediments of Koné Facies and basalts of Poya Terrane (the dating method is summarized in supporting information Text S1). The results show that all the analyzed dolerite dikes/sills crystallized during a relatively narrow time interval in the latest Paleocene and early Eocene (58.4 ± 1.5–47.6 ± 4.0 Ma) (supporting information Data Set S2). It is therefore possible that some of the previously obtained K-Ar ages are related to the same magmatic event and come from unmetamorphosed dolerites. With the exception of a few grains (less than 10%), which show some Pb loss, most zircons display concordant U-Pb ages (Figures 7a and 7c). The dolerite U-Pb ages cluster around 54 ± 5 Ma (Figure 7b), almost the same age as the younger abyssal sediments of the Poya Terrane, a little bit older than preobduction dikes from the Peridotite Nappe (~53 Ma) (Cluzel et al., 2006) and slightly younger than subduction inception at ~56 Ma (Cluzel, Jourdan, et al., 2012).

In the Pouebo eclogitized mélange (north), large mafic blocks of dominantly E-MORB affinity are mixed with metaserpentinite (talcschist). Some yielded U-Pb ages on zircon cores of circa 84 Ma and 55 Ma and recrystallization rims of circa 44 Ma due to HP-LT metamorphism (Pirard & Spandler, 2017; Spandler et al., 2005). Massive eclogite blocks (some may exceed 100 m in size) of the Pouébo mélange, which yield early Eocene magmatic zircons and E-MORB geochemical features, may have parent rocks in Kone dolerites. In contrast, the detrital zircon component of some metasediments of the Pouebo Terrane indicates probable derivation from Upper Cretaceous sediments (Pirard & Spandler, 2017) but the number of dated zircons (eight) is insufficient to be compared to Formation à Charbon or Kone Facies. Therefore, some components of the Pouebo Terrane may have protoliths coming from the Kone Facies. However, the degree of the metamorphism is of such intensity that metasedimentary rocks derived from the Kone Facies could not be recognized in the field.

On the east coast, dolerites crop out discontinuously and are associated with typical fine-grained turbidites of the Kone Facies (supporting information Figures S5a and S5d), which display contact metamorphism (nodular schist). Some of them display strongly heterogeneous deformation due to transcurrent tectonics and strain partitioning. Undeformed (although metamorphosed) thick dolerites of the Thiem Unit (between Hienghène and Touho; Figure 1) display dominantly concordant zircons with the same age (55.9 ± 1.2 Ma) as the rest of the terrane (Figure 7c). However, severely sheared dolerites of the same group of outcrops yield discordant U-Pb zircons ages that span the 58–19 Ma time interval (sample THIEM 3, supporting information Data Set S2). The older population with low U and Th contents is Eocene in age. The younger ones are metamict high U and Th zircons that define a loosely constrained intercept at 26.3 ± 0.6 Ma (Figure 7d). In spite of some uncertainty due to uncomplete reset of the zircon U-Pb system, it appears that dolerites of the Thiem Unit were intruded into Kone Facies sediments at ~56 Ma, as in the rest of the terrane, and have been sheared at ~26 Ma. It is worth noting that the latter event may be time correlated with late Oligocene granitoid emplacement (Paquette & Cluzel, 2007).

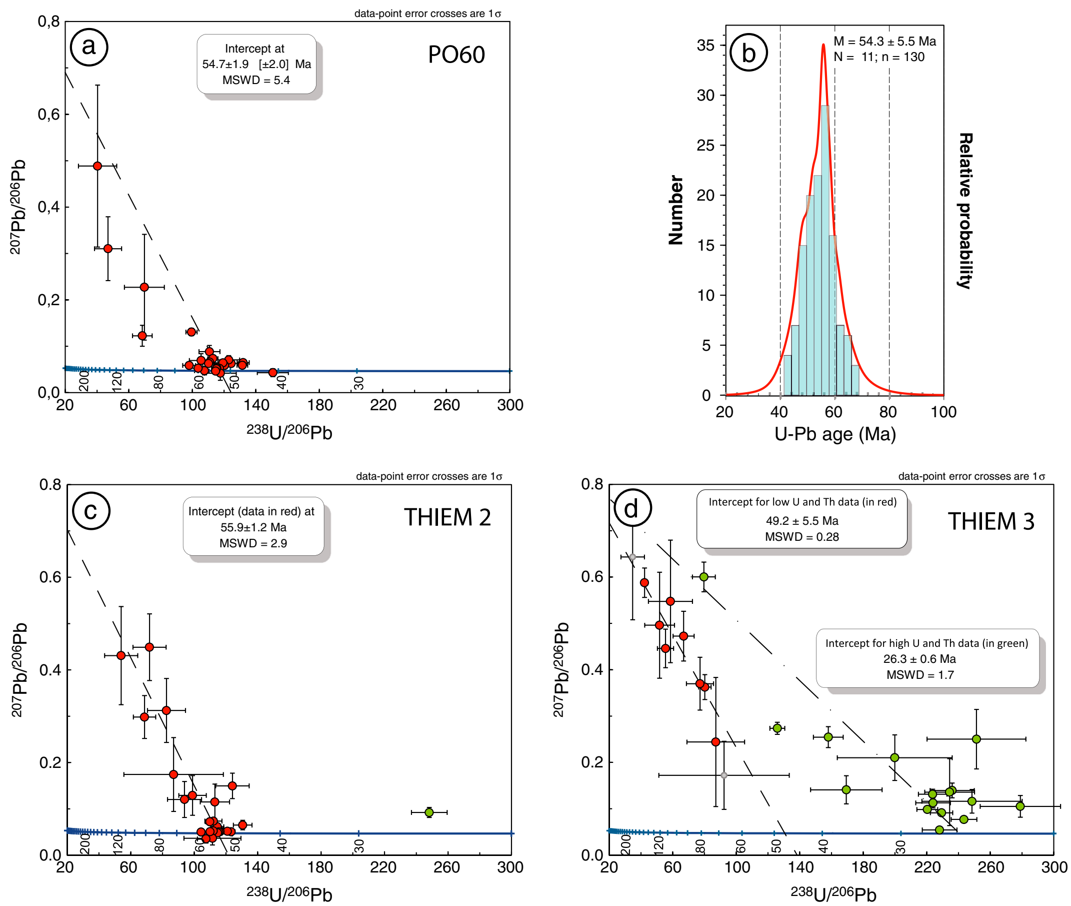

Figure 7. U-Pb microzircon dating of representative dolerite of the Kone Facies (Koné quarry, west coast), (b) cluster around 54.4 Ma of U-Pb microzircon ages of dolerites sills intruded in Kone Facies sediments (supporting information Data Set S2), (c) U-Pb microzircon dating of dolerite of the Kone Facies from the Thiem Unit (east coast), and (d) partial reset of U-Pb microzircon ages of a sheared dolerite of the Thiem Unit to suggest late Oligocene overprint (diagrams elaborated with Isoplot 3 software; Ludwig, 2012).

11. Dolerite Geochemistry and Comparison With Poya Terrane Basalts

Fifteen new representative samples of early Eocene sills and dikes that crosscut the sediments of Koné Facies and basalts of Poya Terrane have been analyzed for major trace elements, and REE at the SARM-CRPG of Nancy France (for analytical procedure, accuracy, and detection limits, see supporting information Text S1). They have been compared with those available in the literature regarding basalts and dolerites of the Poya Terrane (Audet, 2008; Cluzel et al., 2001; Eissen et al., 1998).

All 42 dolerite samples in the data base have very similar subalkaline basalt compositions (46.8 ± 0.6 wt % SiO_2, 1.4 ± 0.2 wt %TiO_2, 14.1 ± 0.7 wt % Al_2O_3, 2.7 ± 0.4 wt % Na_2O, and 0.3 ± 0.1 wt % K_2O) (supporting information Table S3). Considering the relatively high water content (average 2.3 wt % H_2O) and erratic variation of some mobile elements, classification/discrimination based upon "immobile" trace elements has been preferred. On the Zr/TiO_2 versus Nb/Y diagram (Pearce, 1996), which is considered a proxy of the classical TAS diagram of Le Bas et al. (1986) for metamorphosed or slightly altered rocks, all dolerite samples plot in a narrow area, on the high Nb/Y side of the basalt field (Figure 8). In contrast, two subtypes may be identified on chondrite-normalized REE patterns (Evensen et al., 1978; Pearce, 1982) (Figure 9):

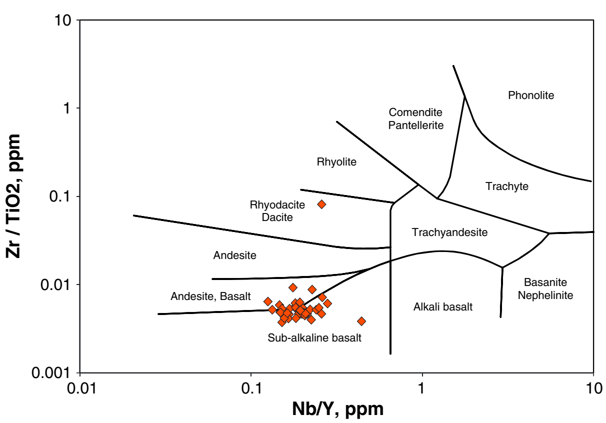

Figure 8. Zr/TiO_2 versus Nb/Y classification diagram for weathered or metamorphic rocks (Pearce, 1996) to show dolerites compositions that dominantly plot in the field of subalkaline basalts.

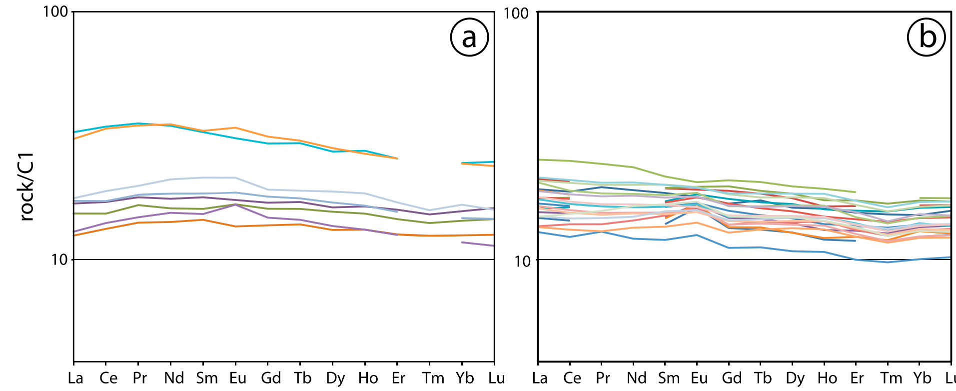

Figure 9. REE diagram of early Eocene dolerites normalized to the chondrite C1 (Evensen et al., 1978). (a) LREE-depleted dolerites in Poya Terrane and Kone Facies. (b) Flat REE patterns of E-MORBs dolerites.

(i) light REE (LREE)-depleted patterns ($(La/Sm)n = 0.91 \pm 0.06$; Figure 9a) similar to the average N-MORB pattern (although their bulk REE content is 2 times higher) (Gale et al., 2013) only represent dikes that crosscut Poya Terrane basalts and (ii) almost flat REE patterns ($(La/Yb)n = 1.2 \pm 0.1$) without depletion in LREE ($(La/Sm)n = 1.00 \pm 0.20$; Figure 9b), some of which crosscut Poya Terrane basalts, while the others represent sills in Kone Facies sediments. The former have been generated from a slightly depleted shallow mantle source, and the latter are diagnostic of E-MORBs (enriched MORBs), e.g., subalkaline basalts slightly enriched in LREE and large-ion lithophile element (LILE) incompatible elements with respect to normal MORB (N-MORB).

On the REE and trace elements expanded spider diagram normalized to the average N-MORB (Figure 10) (Sun & McDonough, 1989), patterns of dolerite dikes and sills of Poya and Kone Facies are all very similar, except two or three samples for which the zigzag pattern probably denotes some analytical issue (incomplete leaching of some accessory minerals?). A negative slope of LREE-depleted patterns (Figure 10a) and undepleted patterns (Figure 10b) and fractionation of LILE with respect to high field strength elements are inconsistent with the MORB-like features of some dolerite samples and probably signal some source heterogeneity, which may be due to near-ridge reenrichment of the mantle source or source mixing (see discussion below).

Dolerite sills in the Kone Facies commonly display a weak Nb negative anomaly (Figure 10b), which is not present in E-MORB dikes crosscutting Poya basalts and is likely due to slight contamination by wall rock terrigenous sedimentary rocks. The scarce occurrence of inherited older zircons (~100 Ma) in some dolerites (supporting information Data Set S1) supports this interpretation.

A single magmatic affinity is suggested by some incompatible trace element ratios, which are considered to reflect source compositions and melting processes. On the Hf/3-Th-Ta triangular diagram of Wood (1980) modified by Vermeesch (2006), E-MORB dolerites plot in a restricted area similar to that of E-MORB flow and pillow basalts of the Poya Terrane (Figure 11). There is no difference in Hf, Ta, and Th ratios between LREE-depleted and LREE-undepleted dolerites, which therefore may come from a mineralogically uniform source. Significantly, in contrast with dikes that crosscut Poya Terrane basalts and have E-MORB and BABB features, the dolerites that intrude the Kone Facies never display BABB signatures.

12. Tectonic Structure and Metamorphism

The Poya Terrane in a strict sense consists of hundreds of upright tectonic slices, a few meters to a few hundred meters thick and a few tens of meters to several hundreds of meters long. In contrast, sediments of the Kone Facies appear in much larger units, which can be followed laterally over several kilometers. The overall structure defined by sedimentary bedding and dolerite sills trends parallel to the orientation of the island (NW-SE). However, it shows prominent variations due to gentle kilometer-scale folds with vertically plunging axes (Figure 1). Away from the basal thrust of the Peridotite Nappe, except the numerous faults, the only noticeable tectonic structure at outcrop scale is meter-scale folds with plunging axes homothetic to those of regional scale. Overall, these folds indicate a dextral shearing, which is also a prominent late feature of the Eocene HP-LT metamorphic complex in the north of the island (Cluzel et al., 2001; Maurizot et al., 1989), and does not appear in the overlying Peridotite Nappe. In west coast units, schistosity only appears

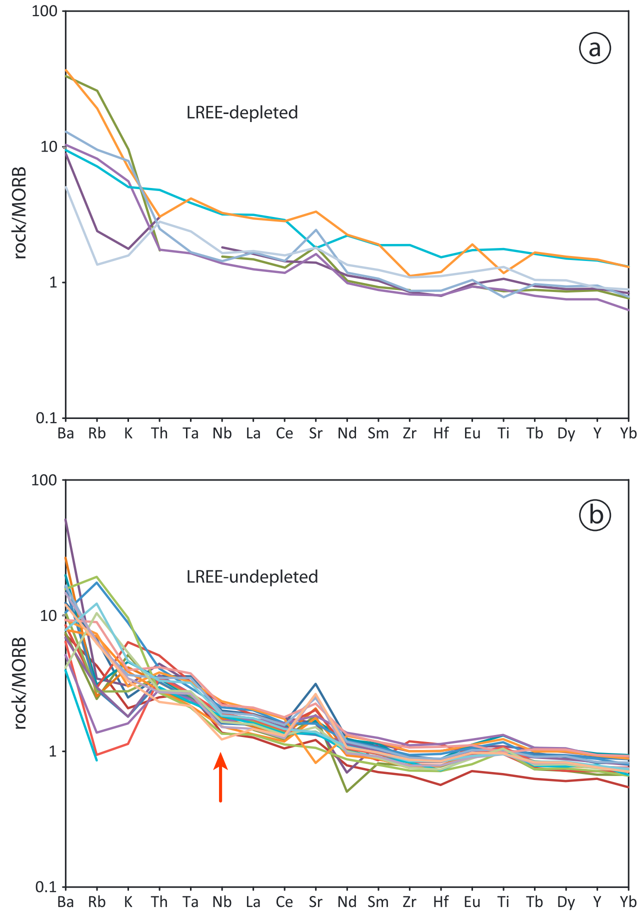

Figure 10. REE and trace elements spider diagram of dolerites normalized to the N-MORB (Pearce, 1982). (a) LREE-depleted patterns. (b) LREE undepleted patterns showing minor Nb negative anomaly possibly due to contamination by host rock.

in sediment lenses in a zone about 100–200 m thick beneath the basal thrust of the Peridotite Nappe and disappears downward; it is roughly parallel to lithologic boundaries whatever their dip. Asymmetrical boudinage of chert beds, S-C, and S-C-C′ structures indicates top-to-the-SW subhorizontal shearing consistent with the overall SW directed motion of the Peridotite Nappe.

The base of the Poya Terrane is rarely well exposed. However, where it can be observed on its northeastern boundary, the underlying autochthonous sediments display a rough schistosity, steeply dipping to the SW, without clear kinematic indications.

No evidence of metamorphism exists in Kone Facies rocks in the main west coast unit, except for contact metamorphism in the vicinity of dolerite sills. Dolerites are also free of any ductile deformation and recrystallization, even immediately beneath the Peridotite Nappe. Poya terrane basalts display zeolite to lower greenschist facies due to hydrothermal alteration (ocean floor metamorphism) and low-grade burial metamorphism (Cluzel et al., 2001; Nicholson et al., 2000). In contrast, in Hienghène and Touho areas (Figure 1), i.e., along the northeastern flank of the large anticlinorium cored by Pouebo and Diahot HP-LT terranes (Figure 2a), the east coast equivalents of Poya Terrane basalts and Kone Facies are closely associated with tectonic lenses of serpentinized peridotite and display evidence for polyphase recrystallization and deformation, which vanishes southeastward. The earliest event is represented by contact metamorphism (recrystallization spots/nodules) developed in Kone Facies turbidites close to dolerite sills (supporting information Figure 5c). In turn, sediments and dolerites developed schistosity and experienced blueschist facies metamorphism, now represented by scarce remains of blue amphibole in metadolerite (supporting information Figures S4a and S4b). Finally, the whole set has been deformed by tight folds in metasediments (supporting information Figure S5b) and, due to higher strength, gentle folds in metadolerite (supporting information Figure 5d). The folds trend N110°E on average are upright or slightly reclined to the south and crosscut by dextral faults with a similar trend. In metadolerites, blueschist facies minerals have been extensively replaced/pseudomorphosed by a lower amphibolite to greenschist facies association (green hornblende, tremolite-actinolite, and chlorite). The high-temperature schistosity is partly overprinted by spaced colder cataclasis. The polyphase evolution of these units may be correlated with the major steps of the evolution of the HP-LT complex: (i) subduction, (ii) exhumation and arching, and (iii) transcurrent (transpressive?) dextral faulting.

13. Discussion

The detrital sediments of the Kone Facies have the same provenance as the autochthonous Formation à Charbon, e.g., mostly the underlying basement terranes, except for Cretaceous zircon populations. The volcaniclastic character of some sandstones and importance of Coniacian-Santonian detrital zircon populations of Kone Facies sediments suggest greater proximity to volcanic centers compared to the autochthonous Formation à Charbon. However, this is in contrast to the absence of Late Cretaceous volcanic rocks in the Kone Facies. Nevertheless, it is worth noting that Kone Facies rocks have no known basement and have been scrapped off the ancient passive margin. Thus, it is possible that some Late Cretaceous synrift volcanic rocks have remained attached to the pre-Late Cretaceous basement and are not exposed at present. Alternatively, Late Cretaceous zircons may have come from an as yet undiscovered Late Cretaceous volcanic arc, which could have been rifted away eastward to form the basement of Loyalty or Fiji islands.

The upward and possibly lateral transition of sandstones into finer-grained turbidites and finally pelagic argillites records Late Cretaceous deepening and progressive interruption of clastic input due to postrift

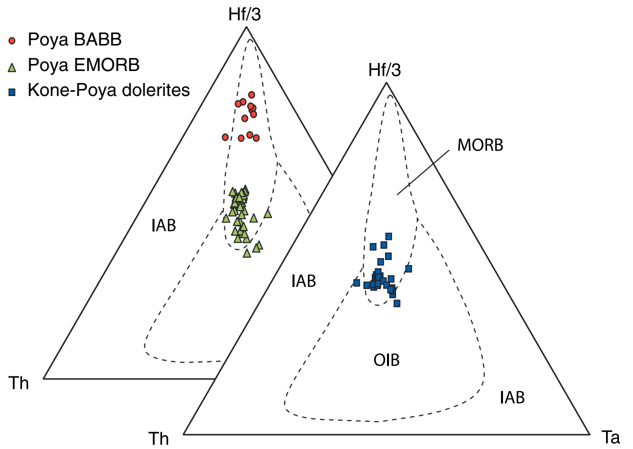

Figure 11. Hf/3-Th-Ta ternary diagram of Wood (1980) modified by Vermeesch (2006) to compare discriminant trace elements ratios of Poya Terrane basalts (BABB and E-MORBs) and dolerite sills and dikes that crosscut both Poya and Kone Facies rocks.

submersion and thermal subsidence. This evolution is similar to that of Formation à Charbon. Some differences exist, however, because the latter accumulated in shallower half-grabens and was followed by deposition of hemipelagic black cherts and micrites, which are not present in the Kone Facies. Instead, upward evolution toward bathyal siltstone and argillite suggest that Kone Facies sediments are intermediate between Formation à Charbon and bathyal argillite of the Poya facies in a strict sense. Intermixing of distal turbidites and abyssal red argillite suggests that Kone Facies sediments accumulated on the eastern passive margin of the Norfolk Ridge immediately before and during oceanization of the South Loyalty Basin in Campanian time. From the origin of Kone-Poya clastic sediments and abyssal rocks in the eastern passive margin of the Norfolk Ridge, and occurrence of HP-LT minerals, we infer that both belong to the lower plate of the obduction/subduction system, thus reinforcing the accretion model.

The large difference that exists between strongly disrupted Poya Terrane basalts and Kone Facies rocks, which form extensive units, suggests contrasting modes of tectonic emplacement. Small-scale basalts and abyssal argillite slices have been peeled off the downgoing plate and accreted to the intraoceanic Loyalty fore arc. In contrast, rock units of the Kone Facies may result from the tectonic inversion of the Late Cretaceous passive margin. They have been possibly detached as one or several coherent units and thrust southwestward to their present location to the northeast of Poya Terrane basalts.

The formation of a dolerite sill complex temporally correlates with subduction inception and suggests some genetic link. However, there is a great difference between E-MORB sills of the lower plate, and the various subduction-related dikes that crosscut the Peridotite Nappe (upper plate), which are related to different processes.

E-MORBs are generally thought to form in off-axis seamounts and magma lenses a few kilometers away from the ridge (Han et al., 2014); they may also erupt at the ridge axis (Schilling et al., 1983; Waters et al., 2011) and are generally minor compared to N-MORB in normal oceanic basins. Alternatively, they may be an important component of some marginal basins, especially those with multiple ridge junctions. Formation of E-MORBs in the South Loyalty Basin is consistent with their appearance in modern back-arc settings such as the North Fiji (Eissen et al., 1994) and Lau basins (Volpe et al., 1988). E-MORBs may form by (i) mixing of shallow (depleted) and deeper (fertile) mantle sources (Waters et al., 2011), (ii) contamination of the asthenosphere by subducted OIB seamounts (Ulrich et al., 2012), or, alternatively, (iii) may result from two-stage partial melting of one single source (Donnelly et al., 2004). EMORBs of the Poya Terrane have enriched geochemical and isotopic signatures and coexist with BABBs coming from a depleted (N-MORB-like) source (Cluzel et al., 2001). Therefore, the two-stage melting model does not apply. The existence of a relatively wide range of isotopic compositions in E-MORBS of the Poya Terrane (2.5 < εNd < 6.6) having the same trace element features (i.e., REE-Tr patterns and Hf/Th; Figure 12) suggests source mixing or mantle heterogeneity.

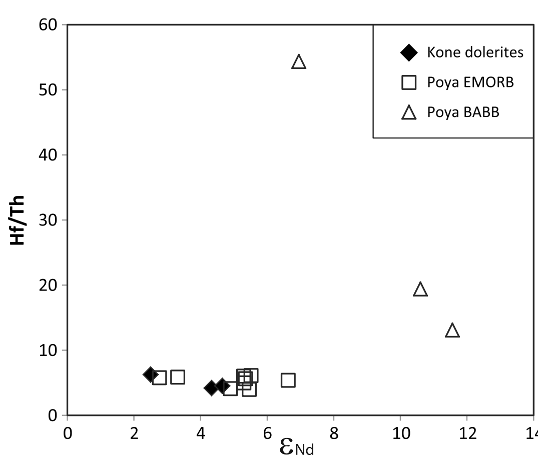

Figure 12. EpsNd versus Hf/Th diagram to show variable εNd ratios of E-MORB dolerites with similar trace-elements ratios, thus suggesting source mixing. Data with white symbols are from Cluzel et al. (2011); data with plain symbols are from this study (E-MORB sills from Kone Facies; supporting information Table S4).

Whatever the processes involved in their formation, eruption into the ancient passive margin of E-MORBs with geochemical and isotopic signatures similar to those of the South Loyalty Basin itself (Figures 11 and 12) ~25–30 Ma after the end of rift-related magmatism represents a difficult issue.

Eruption of E-MORBs far away from the spreading ridge seems difficult unless they have been horizontally channeled over long distances by lithosphere-scale faults, a process advocated under some

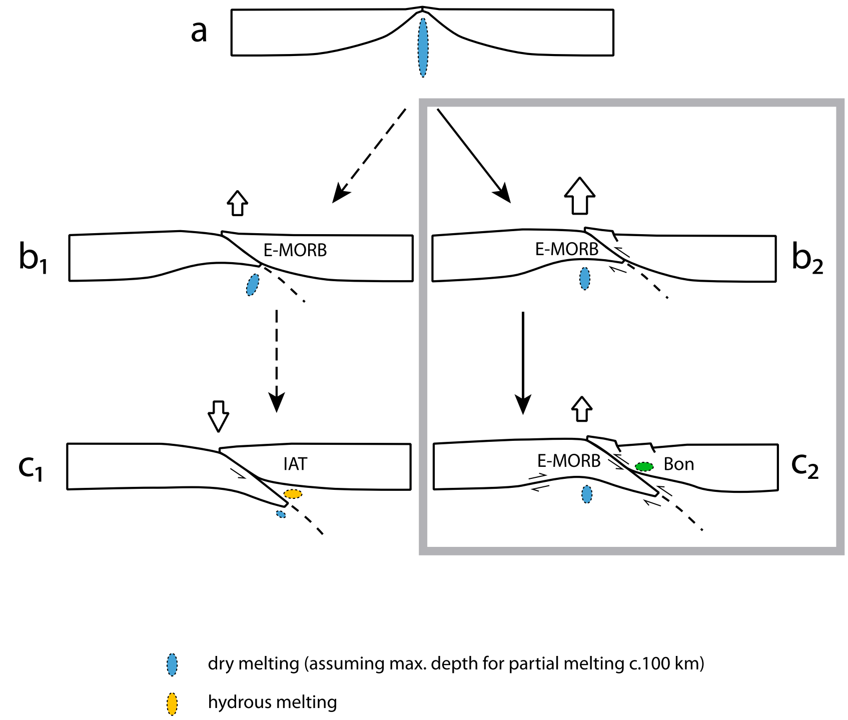

Figure 13. Two possible scenarios for the inception of early Eocene subduction: (b1 and c1) subduction of the partial melting zone (ridge) and eruption of EMORB in the upper plate and (b2 and c2) preferred scenario with EMORB erupted in the lower plate.

circumstances, e.g., in the Dead Sea Fault system (Weinstein & Garfunkel, 2014) or in parts of the giant Central Atlantic Magmatic Province (Nomade et al., 2000). However, no evidence for such a magma transfer appears in paleotransform faults identified in the Peridotite Nappe of New Caledonia.

Generating E-MORB out of a spreading ridge requires uplift of the asthenosphere that cannot be achieved without prominent lithosphere thinning. A transcurrent regime could generate MORB-like magmas within a narrow zone (pull-apart) consistent with the location of Kone dolerites within the ancient passive margin. However, mantle upwelling and partial melting would have first generated deeper-sourced alkaline (OIB-like) magmas followed by shallower subalkaline MORB-like magmas.

Alternative scenarios involve evolution of the ancient spreading ridge after subduction inception at or near the ridge at circa 56 Ma (Figure 13): (i) either the ridge was subducted together with the lower plate, then the partial melting zone should have generated similar melts (E-MORBs and BABBs) in the upper plate and died out quickly by the effect of increasing pressure (Figure 12b1) before being relayed by incipient volcanic-arc activity (Figure 12c1). However, Eocene E-MORBs and BABBs are absent in the upper plate (the Peridotite Nappe) and this model does not apply. Alternatively, (ii) the melt zone may have remained at the same place by delamination of the lithosphere, swept the lower plate continentward, and, for a while, continued to generate E-MORB melts, which were erupted together with prominent uplift (Figure 12b2). This model is consistent with eruption of boninite series magmas directly over peridotites of the upper plate (Marchesi et al., 2009; Pirard et al., 2013; Cluzel et al., 2016) (Figure 12c2). The second scenario, which fits well with the overall features of the Peridotite Nappe, will be preferred although ridge subduction is generally advocated in subduction inception models (Gurnis, Hall, & Lavier, 2004, and references herein). It is worth noting that emplacement of E-MORB sill complex was synchronous with temporary emersion of autochthonous units during the late Paleocene (Adio limestone) (Maurizot, 2013), which records localized uplift of the Norfolk Ridge in possible relation with its entry in the flexural fore-arc bulge. Alternatively, increase of compressional stress may have occurred due to progressive subduction jamming by buoyant crust elements (Diahot Terrane) (Figure 3). In addition to a fore-arc bulge, arching of the ancient Late Cretaceous margin may have been enhanced by subplate heating by the almost extinct partial melting zone (see below).

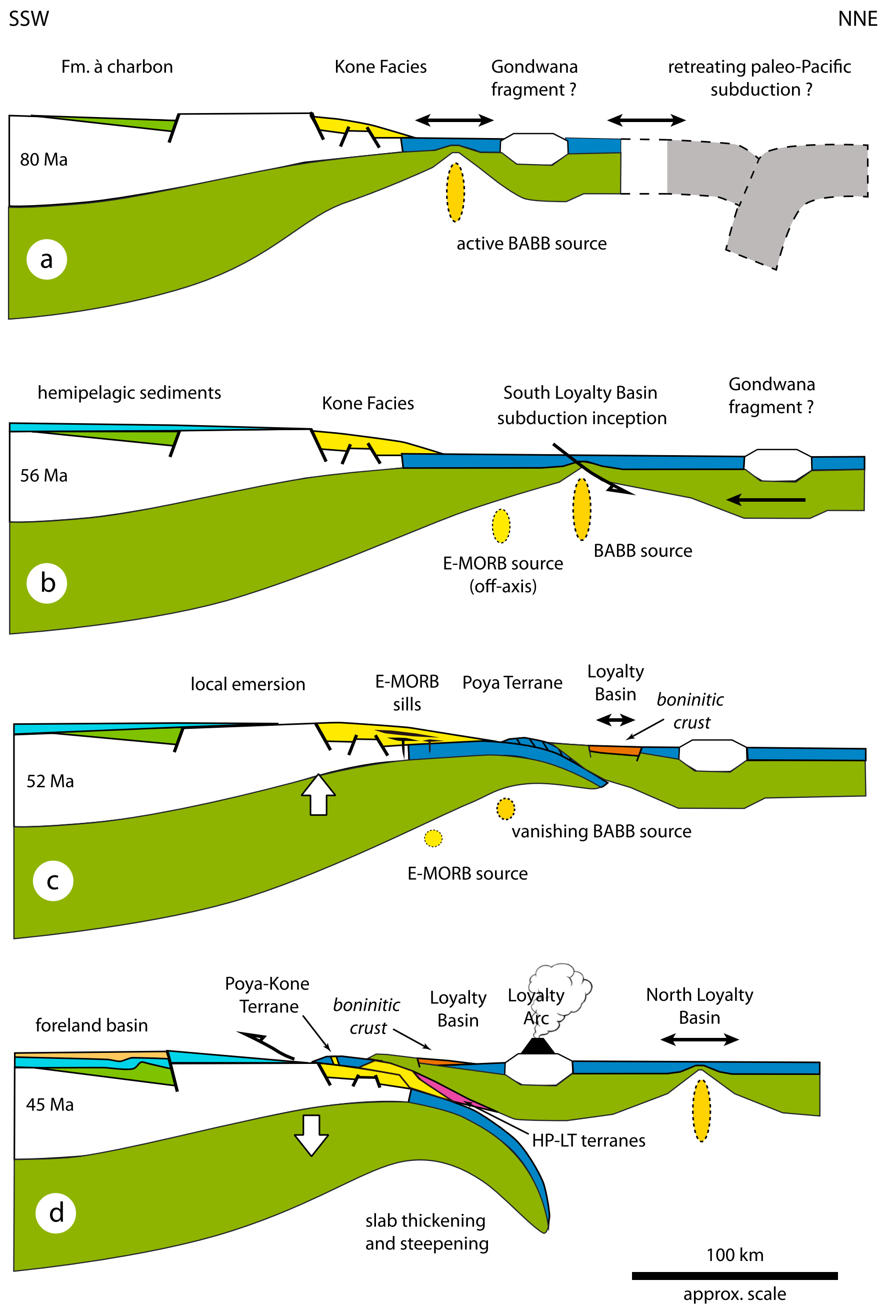

Figure 14. Geodynamic model for the evolution of Poya Terrane from subduction inception to obduction.

Explaining why the EMORBs that intruded Kone Facies sediments have been emplaced as sills instead of forming dikes is crucial for constraining the tectonic evolution of the Eocene subduction/obduction complex. Sheeted sill complexes which occur in the oceanic crust record an imbalance between crustal extension and magma supply (Hopson, 2007). This is obviously the case in Kone Facies rocks because extensional tectonism had already stopped since 25–30 Ma at the time of intrusion, thus preventing magma ascent. However, the situation of the ancient Late Cretaceous margin at the Paleocene-Eocene boundary was not that of an oceanic ridge.

Sills and laccoliths may also form in compressional settings (Kavanagh et al., 2006; Menand et al., 2010), and subduction of young and buoyant oceanic lithosphere generally results in horizontal compressive stress, while the obliquity of the lower plate with respect to the trench generates an oblique component to the convergence. In New Caledonia, transpression is recorded by the occurrence at all scales of folds with steeply plunging axes, consistent with dextral transcurrent tectonics, which are not present in autochthonous units or in the overlying Peridotite Nappe. Therefore, it appears that accretion of oceanic crust and passive margin elements occurred during dextral oblique subduction (Figure 3) (Cluzel et al., 2001), which may have reactivated ancient structural features of the passive margin. Active faulting may have channeled upward or horizontal magma transit at depth, while at a shallower level, the decreasing lithospheric pressure favored vertical tensile stress and enhanced formation of sill/laccoliths (Corry, 1988; Tibaldi et al., 2008).

A geodynamic model accounting for these new elements may be proposed. However, it is worth noting that sketch cross sections of Figure 14 cannot completely account for the evolution of the eastern Norfolk margin, which at least during its last stages developed in a transcurrent setting (Figure 3).

During the Coniacian and Santonian, extreme thinning of SE Gondwana margin generated grabens/hemigrabens in which terrigenous sediments were deposited. Rifting was followed by Campanian-Paleocene development of oceanic lithosphere and formation of a passive margin on which deep water turbidites accumulated, isolated several ribbons of continental crust, and generated Poya Terrane basalts from a heterogeneous (BABB and EMORB) mantle source (Figures 14a and 14b).

In latest Paleocene-earliest Eocene time, shallow-dipping subduction started near the ridge and inverted the basin. Poya Terrane basalts were obliquely accreted in the nascent Loyalty fore arc. The Loyalty fore arc probably underwent uplift and erosion, leaving only deeply unroofed peridotites. Meanwhile, the partial melt zone swept the base of the lower plate and generated dikes in the marginal basin lithosphere and sills in the ancient passive margin. Localized uplift and emersion of Norfolk Ridge may be correlated with this event (Figure 14c). Meanwhile, slab melts and ultradepleted magmas were generated in the mantle wedge and formed the early Eocene dike set and boninite-series fore-arc crust. When the ancient passive margin reached the convergence zone, Poya basalts and Kone Facies were amalgamated and thrust together on autochthonous units (Figure 14d) where they fed the middle to late Eocene syntectonic basins. Finally, the whole set was thrust by (actually subducted beneath) the Peridotite Nappe, which was again uplifted and eroded, preserving only scarce remains (cumulates) of the fore-arc crust.

14. Conclusion

A reappraisal of the Poya Terrane based upon field data, sediment analysis, U-Pb zircon geochronology, and whole-rock geochemistry has revealed the following:

1. The extent of the main sedimentary component, referred to as Kone Facies, had been largely underestimated and actually represents about one third of the bulk terrane surface.
2. These sediments are composed of sandstones and distal turbidites overlain by abyssal argillites, which accumulated on the eastern passive margin of the Norfolk Ridge during rifting and postrift thermal subsidence.
3. Kone Facies sediments are about the same age and of similar provenance as the autochthonous Late Cretaceous Formation a Charbon, with a greater amount of detrital zircon coming from contemporaneous magmatism.
4. Instead of derivation through the accretion of Late Cretaceous-Paleocene marginal basin crust, the mafic magmatic component of Kone Facies formed as early Eocene sills of E-MORB affinity generated close to the time of subduction inception.
5. The predominance of E-MORBs over BABBs in the oceanic component of the Poya Terrane should be reevaluated because fresher E-MORB dolerites have been oversampled.
6. At variance with previous interpretations, the lower plate (South Loyalty Basin) of the subduction/obduction complex was probably of BABB affinity. This is consistent with the composition of high-temperature amphibolites (metamorphic sole) and that of slab melts intruded in the upper plate (the Peridotite Nappe).
7. Slices of Poya Terrane basalts were accreted at shallow depth in front of the Loyalty fore arc. In contrast, some elements were dragged down by tectonic erosion, subducted, and formed the Pouebo eclogitic mélange

8. The northeastern elements of the Poya Terrane (including Kone Facies) that crop out on the east coast were subducted to depth sufficient for the development of blueschist facies metamorphism. Together with involvement of passive margin sediments, this excludes any possibility that the Poya Terrane originated from the upper plate (fore arc) of the subduction-obduction system.
9. Late Oligocene reset of the U-Pb zircon system confirms the widespread occurrence of brittle tectonics and hydrothermal activity contemporaneous with postobduction granitoid intrusion, which largely exceeds their area of occurrence in southern New Caledonia.

New Caledonia shows exceptional preservation of an example of subduction/obduction system, which was not obscured by subsequent continent-continent collision. It appears that off-peeling of the lower plate crust and accretion tectonics may generate large mafic allochthons, forming disrupted bodies in suture zones. On a local scale, these mafic units are closely (within a few kilometers) associated with eclogites of similar composition that were exhumed through the subduction channel independently of continental collision.

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